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Salinity status of the 2011 Tohoku-oki tsunami affected agricultural lands in northeast Japan

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Abstract

As Japan has abundant annual rainfall (1,000 to 2,500 mm), soil salinity of agricultural lands has rarely been a major problem. Following the 2011 earthquake in the Pacific, large stretches of land along the coast in northeast Japan were devastated by a powerful tsunami. Saltwater damage of agricultural lands was so severe that agricultural crops could not be grown on large parts of the tsunami-inundated farmlands even two years after the disaster. This paper summarizes the status of agricultural lands in northeast Japan's Tohoku region that were affected by the tsunami. The paper presents the results of a field study of agricultural lands in Miyagi Prefecture, where the extent of the seawater damage was the most severe, representing 67% of the total tsunami-affected agricultural lands. Forty samples from surface and underlying (undisturbed) soil were collected from 30 different locations in coastal and tsunami-inundated farmlands and from inland sites located beyond the limit of the tsunami inundation. The analyses and measurements showed that the extent of soil salinity varied greatly across these sites, with the highest electrical conductivity (EC) value of 3.72 dS m^{-1} found in the surface soil of Minamisanriku cho. In addition, two study sites adjacent to each other, Watari cho and Yamamoto cho, had maximum and minimum EC values of 2.0 dS m^{-1} and 0.21 dS m^{-1}, respectively, in their underlying soils. A comparison of the major soil properties revealed that the salinity status of the tsunami-inundated farmlands was dependent on particle size distribution and therefore on the infiltration rate of the soil, as well as the relative physical position (elevation) of the farmland. This study led us to carry out further investigations and experiments (still on-going) related to restoration and mitigation work in the tsunami-inundated agricultural lands, giving the highest priority to the major soil properties of different field sites in Miyagi Prefecture.

KeyWords: Agricultural land, Salinity, Soil properties, Tsunami, Northeast Japan

1 Introduction

The northeast region of Japan known as the Tohoku region consists of six prefectures: Akita, Aomori, Fukushima, Iwate, Miyagi and Yamagata. The region, like other parts of the country, generally has plentiful precipitation, with an average annual amount of 1,360 mm and good sources of freshwater to support agriculture, as well as the livelihood of the farmers. About a million people live in a total area of 66,890 km^2, nearly one-fifth of Japan's total area (377,944 km^2) with less than one-tenth of the country's total population. Japan is one of the most earthquake-prone places on Earth, accounting for no less than 10% of all tremors worldwide, despite making up just 0.3% of the world's total land mass. A magnitude-9.3 massive earthquake (named the 2011 Tohoku-oki earthquake/tsunami) struck off the coast of northeastern Japan on March 11, 2011, sending a huge tsunami smashing into the country's northeastern coastal area. In the disaster, 23,600 hectares of farmland were inundated by the tsunami in the six prefectures that face the Pacific Ocean. These include four prefectures in the Tohoku region (Aomori, Fukushima, Iwate and Miyagi) and two adjacent prefectures (Ibaraki and Chiba) in Kanto region (Fig. 1). In addition to flooding farmlands with saltwater and debris, the tsunami damaged many irrigation and drainage systems (MAFF,

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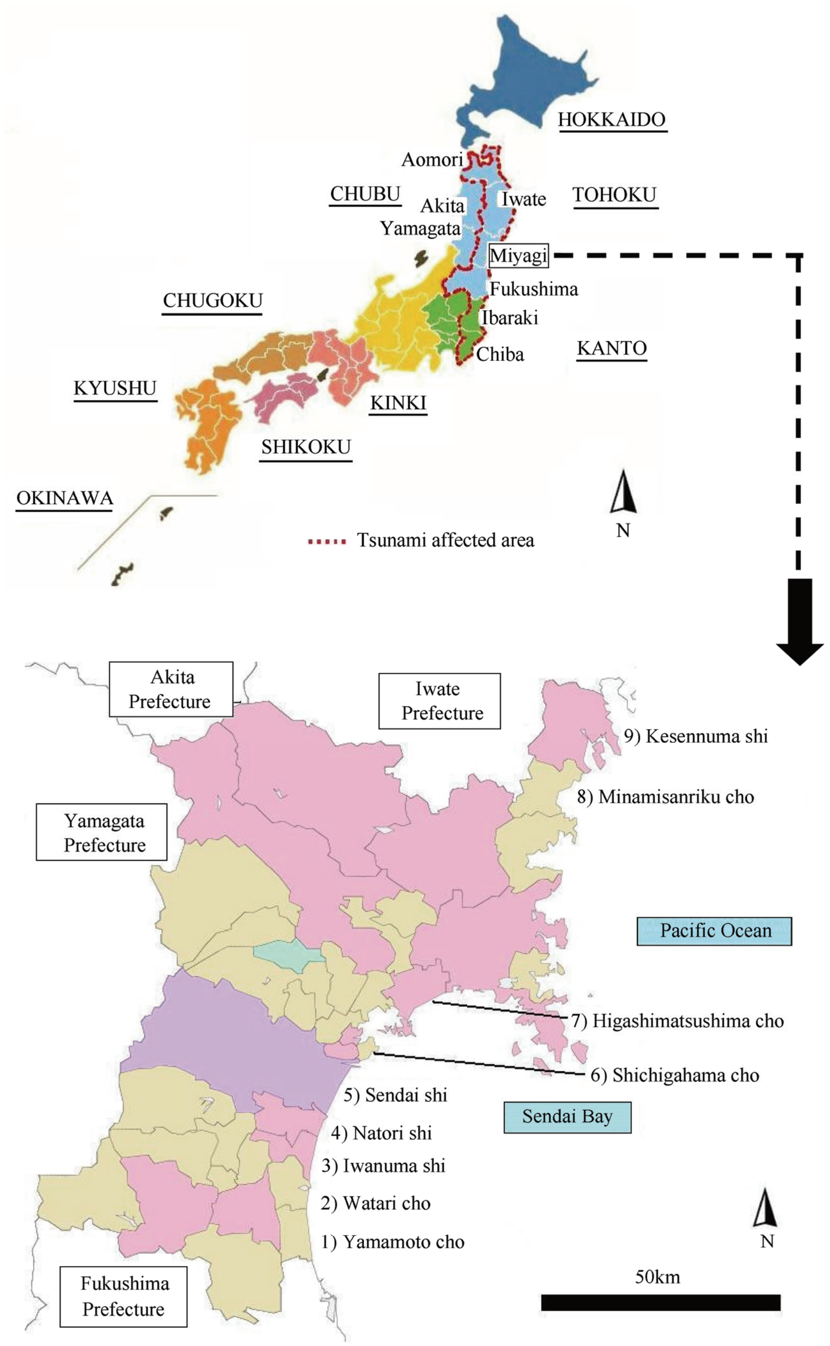

Fig. 1 Tsunami-inundated regions and prefectures in northeast Japan after the 2011 Tohoku-oki tsunami (top) and the study area (Miyagi Prefecture) with the soil-sampling sites (bottom)

2011a). Almost 85% of the tsunami-inundated farmlands in the northeast region were paddy fields and the remaining 15% were uplands (MAFF, 2013) with crops and vegetables such as wheat, soybean, potato, cabbage, onion, radish and cucumber. The salinity level of topsoil mixed with the tsunami deposits reached a maximum electrical conductivity (EC) value of 37.8 dS m^{-1}, whereas the pre-tsunami average EC value of the soil in most of the agricultural lands was below 1 dS m^{-1}(Haraguchi et al., 2012).The deposited salt disrupted crops by hindering their ability to absorb water and nutrients. Thus, the farmlands could not be used to produce crops for some time after the seawater intrusion.The Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF) devised a detailed master plan (MAFF, 2011c) and initiated large-scale recovery/remedial works in the tsunami-induced farmlands. According to a progress-report (MAFF, 2013), 39% of the farmlands have been completely reclaimed, and are now suitable for plant cultivation, and the rest are expected to be completed by 2015. Most of the salinity mitigation works recommended by

MAFF (MAFF, 2011b) used diggers and other machines to sieve and clean the tsunami-deposit-mixed soil particles, to remove/excavate the upper soil layer (to remove tsunami deposits/salts from the soil particles), and/or to transport the alien soil from nearby mountains. These methods can clean the soil particles. However, they cannot enable full recovery of agricultural soil productivity because this is dependent on a variety of phenomena derived from the physico-chemical and biological status of topsoil under long-term natural conditions. Mechanical sieving/cleaning can detach the impurities and improve the hydraulic conductivity of the soil particles. However, it also breaks down aggregates and disrupts microbiological activities, which are very important, particularly for upland soils. On the other hand, puddling and flushing of soil particles with freshwater (rainwater) is the best option for treating saline soil in paddy/lowland fields. However, in the tsunami-torn fields, damaged irrigation and drainage systems further slowed the removal of salt from the upper crust in many cases (Inui et al., 2012).

Since the tsunami disaster, most research carried out on agricultural lands has focused on the extent of the salinity of the topsoil based on measurements and analyses of major chemical elements/water-soluble ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Br^- and Cl^-) carried by the tsunami seawater. However, in practice, the topsoil of large areas of farmland was covered by tsunami deposits with different thicknesses, and the surface of the fields are not flat, making it difficult to distinguish and measure the amount of original topsoil and the seawater-borne ions. As a result, it is difficult to identify a clear difference in the ratios of the tsunami-inundated soil and the tsunami deposits (Yoshii et al., 2012; Goto et al., 2012). In particular, the thickness of the tsunami deposits varied greatly in the paddy fields, which are typically fragmented and bounded by ridges. Therefore, we carried out a comprehensive field survey to assess the salinity status of soils, focusing mainly on upland fields in Miyagi Prefecture where the seawater damage was the most severe, representing 67% of the total tsunami-affected agricultural lands in northeast Japan. The purpose of the study was to determine possible reasons for the soil properties and salinity status of the soil in the tsunami-affected agricultural lands in the northeast region of Japan. Specifically, this paper presents the findings of our field investigations of different agricultural lands (uplands) in Miyagi Prefecture. It traces the development of soil salinity concepts, explores the use of major physico-chemical and biological properties of agricultural soil as determinants of soil salinity, and presents challenges and opportunities for soil conservationists to play a relevant role in the assessment and advancement of saline soil recovery by developing specific soil properties as pre-indicator(s) of salinity mitigation in agricultural lands.

2 Research methodology

2.1 *Soil salinity status after the tsunami*

To better understand the devastation of farmlands caused by the 2011 post-earthquake tsunami in northeast Japan, the damage and the recovery status as of March, 2013 are summarized in Table 1.

Table 1 **Estimated farmland damage by the tsunami and recovery status in different prefectures of northeast Japan**

Prefecture	Region	Total arable land (km^2)	Total flooded area (km^2)	Seawater intrusion (km^2)	Total inundated farmland (km^2)	Ratio of damaged farmland (%)	Recovery by 2013 (%)
Aomori	Tohoku	1,568	24	1	0.79	0.1	94.4
Iwate		1,539	58	2	18.38	1.2	22.2
Miyagi		1,363	327	4	150.02	11	33.3
Fukushima		1,499	112	8	59.23	4	9.3
Ibaraki	Kanto	1,752	23	3	5.31	0.3	90.1
Chiba		1,288	17	2	2.27	0.2	100
Total		9,009	561	20	236		

Source: MAFF, 2013

2.2 *Study area and sampling*

The field survey in Miyagi Prefecture where the tsunami inundation extended up to 4.5 km inland (Goto et al., 2012) was carried out from July 12 to 15, 2012, roughly a year and a half after the tsunami on March 11, 2011. As stated earlier, only upland fields (farmlands) were selected for soil sampling in this study that covered coastal farmlands (henceforth, C), tsunami-inundated farmlands close to the maximum tsunami run-up position (henceforth, T), and inland sites located beyond the limit of the tsunami inundation (henceforth, I). The sites were in 9 different places from the south to the north border of Miyagi Prefecture (Fig. 1). The sampling sites were selected based on reports of devastation caused by the tsunami (MAFF, 2011b) and the distribution of agricultural fields in Miyagi Prefecture. During the survey, we observed that the tsunami deposits on the surface of the sampling sites consisted of sand layers of different thickness (a few centimeters to tens of centimeters). Therefore, we collected soil samples at two different depths of 5 cm and 45 cm from the land surface to obtain representative soil from the crop root zone at each tsunami-inundated (T) location. Forty samples were collected from the surface soil (at a depth of 5 cm) and the underlying soil (at a depth of 45 cm) from 30 different locations. The sampling included some additional samples from three experimental plots near the surveyed locations where different salinity mitigation experiments are undergoing. Disturbed soil was collected with a scoop and packed in airtight polyethylene sacks. Undisturbed soil was collected with a 100 cc core sampler (Dik-1601; Daiki Rika Kogyo, Japan). The collected samples were stored at room temperature until used for analysis. The position of each sampling location (latitude, longitude, and elevation) was recorded with a Global Positioning System receiver (Garmin etrex; Garmin Ltd., USA). Table 2 summarizes the sampling details of the survey, and Fig. 2 and 3 show the pattern and the method of sampling, respectively.

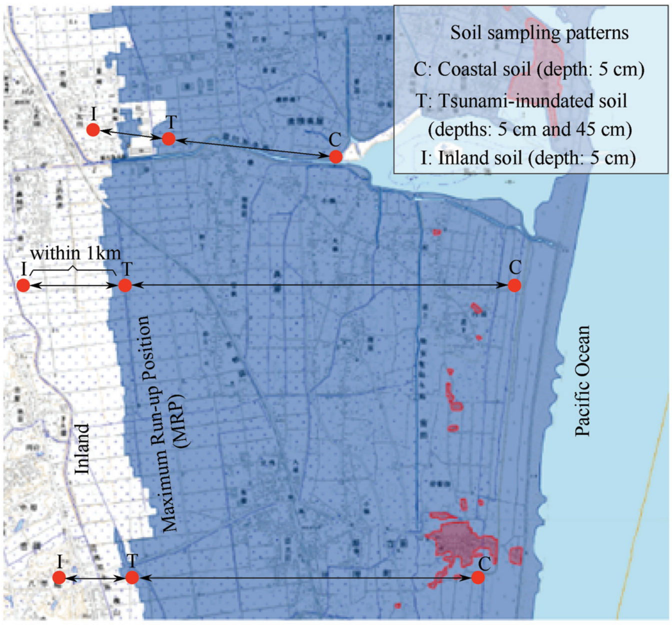

Fig. 2 Sampling patterns at the inland (I), tsunami-inundated (T), and coastal side (C) locations for a single site

2.3 *Measurement and analysis*

During the survey, we measured the *in-situ* EC value of the surface soil at each location using a W.E.T sensor (DIK-691A; Daiki Rika Kogyo, Japan) coupled to a time-domain reflectometer. The EC values (dS m^{-1}) of all the samples, as well as their pH values, were later analyzed in the laboratory, together with other physico-chemical and biological properties of the soil samples, including hydraulic conductivity (cm s^{-1}), particle size distribution (sand-silt-clay ratio), organic matter content (OMC, %), and concentrations of major water-soluble ions. The soil samples inside the polyethylene sacks were air dried, sieved through a 2 mm mesh, and the residues removed with tweezers.

The pH and the EC of the soil were measured with a pH meter (Twin pH B-212; Horiba, Japan) and an EC meter (B-173; Horiba, Japan), respectively. The ratio of soil to deionized water was 1:2.5 for pH, and 1:5 for EC. The particle size distribution of the soil was measured with the pipette method based on Stoke's law, and the saturated hydraulic conductivity (SHC) of the undisturbed samples was measured with a falling head permeameter (DIK 4000; Daiki Rika Kogyo, Japan) based on Darcy's law. We did not measure the particle size distribution of the underlying soil collected from Iwanuma shi, Natori shi, and Sendai shi because the sites are very close to each other (Table 2). In addition, we could not collect a core sample at the Kesennuma shi site because the underlying surface was full of rocks and too hard to penetrate. The OMC of the soil was estimated with the loss-on-ignition (%) method using a muffle furnace (KBF-748; Koyo Thermos, Japan).

Fig. 3 Sampling method of surface (disturbed) and underlying (undisturbed) soil at different sampling sites in Miyagi, 2012

Table 2 Detail of sampling positions and methods of the survey in Miyagi, 2012

Area and approximate distance	Location	Sample No.	Depth (cm)	Sampling position		Elevation (m)
				Latitude	Longitude	
Yamamoto cho	Coastal (C)	1	5	37° 55′ 1.32″ N	140° 55′ 10.32″ E	3
↑	Tsunami (T)	2	5	37° 55′ 35.76″ N	140° 54′ 20.82″ E	4
10km		3	45			
↓	Inland (I)	4	5	37° 56′ 9.24″ N	140° 52′ 53.28″ E	22
Watari cho	Coastal (C)	5	5	38° 32′ 26.94″ N	140° 54′ 58.74″ E	6
↑	Tsunami (T)	6	5	38° 2′ 54.06″ N	140° 53′ 47.46″ E	5
10km		7	45			
↓	Inland (I)	8	5	38° 1′ 47.1″ N	140° 51′ 50.04″ E	6
Iwanuma shi	Coastal (C)	9	5	38° 6′ 6.18″ N	140° 55′ 44.88″ E	8
↑	Tsunami (T)	10	5	38° 6′ 18.78″ N	140° 54′ 16.26″ E	5
9km		11	45			
↓	Inland (I)	12	5	38° 6′ 23.46″ N	140° 51′ 9.72″ E	5

Continued

Area and approximate distance	Location	Sample No.	Depth (cm)	Sampling position		Elevation (m)
				Latitude	Longitude	
Natori shi	Coastal (C)	13	5	38° 16′ 34.5″ N	140° 55′ 16.98″ E	7
↑ 12km ↓	Tsunami (T)	14	5	38° 10′ 28.56″ N	140° 54′ 57.6″ E	9
		15	45			
	Inland (I)	16	5	38° 10′ 10.14″ N	140° 53′ 56.52″ E	8
Sendai shi	Coastal (C)	17	5	38° 14′ 43.44″ N	140° 57′ 9.9″ E	9
↑ 20km ↓	Tsunami (T)	18	5	38° 15′ 11.52″ N	140° 58′ 38.7″ E	2
		19	45			
	Inland (I)	20	5	38° 10′ 20.46″ N	140° 56′ 29.82″ E	3
Shichigahama cho	Coastal (C)	21	5	38° 18′ 28.02″ N	141° 4′ 49.68″ E	5
↑ 40km ↓	Tsunami (T)	22	5	38° 18′ 37.92″ N	141° 4′ 14.82″ E	2
		23	45			
	Inland (I)	24	5	38° 18′ 5.04″ N	141° 3′ 27.66" E	37
Higashimatsushima shi	Coastal (C)	25	5	38° 23′ 14.58″ N	141° 10′ 41.1" E	3
↑ 50km ↓	Tsunami (T)	26	5	38° 24′ 35.4″ N	141° 11′ 48.96" E	9
		27	45			
	Inland (I)	28	5	38° 25′ 54.9″ N	141° 11′ 40.98″ E	7
	Coastal (C)	29	5	38° 40′ 49.56″ N	141° 26′ 45.78″ E	7
Minamisanriku cho	Tsunami (T)	30	5	38° 41′ 31.8″ N	141° 25′ 47.1″ E	17
		31	45			
↑ 40km ↓	Inland (I)	32	5	38° 42′ 1.98″ N	141° 24′ 49.08″ E	41
	Coastal (C)	33	5	38° 46′ 19.68″ N	141° 30′ 32.34″ E	3
Kesennumashi	Tsunami (T)	34	5	38° 46′ 28.98″ N	141° 29′ 34.62″ E	7
		—	45			
	Inland (I)	35	5	38° 41′ 45.42″ N	141° 30′ 43.5″ E	71

—Not measured.

Notes: 1) C indicates the soil samples from the coastal farmlands, T denotes those from the tsunami inundated farmlands, and I indicates those from the inland farmlands located beyond the tsunami inundation limit.

2) Forty samples in total were collected, of which five were obtained from three nearby experimental plots not used in the analysis of this study.

The concentrations of the major water-soluble ions of Na^+, K^+, Mg^{2+}, Ca^{2+} , Cl^-, NO_3^-, SO_4^{2-}, and NH_4^+ were measured with the ion-chromatography method (ICA-5000 system ion-chromatograph, auto-sampler ICA-5450). The ratio (weight/volume) of the air-dried soil to deionized water was 1:5.

3 Results and discussion

3.1 *Soil salinity and recovery status*

The process and mechanism of soil salinity following the seawater intrusion during the post-2011 Tohoku-oki earthquake tsunami is not complex. However, the removal and mitigation of salts (reclamation) in agricultural soil is quite complex, expensive, time and labor intensive, and often dependent upon many factors, such as soil properties, the quality and availability of freshwater, irrigation and drainage facilities, and plant productivity. Based on experiences of past tsunamis, experts estimate that if there is available freshwater (rainwater) and proper drainage facilities, then soil could be returned to its original (pre-tsunami) salinity levels within two years (Plett, 2012). However, the present recovery status (Table 1) shows that the major portions of the salinity remedial works remain incomplete two years after the tsunami. Moreover, farmers are not satisfied with the productivity level of the reclaimed farmlands (The Daily Yumiuri, March 8, 2013). The government in Japan (MAFF) and various organizations/groups have taken serious steps to remediate the saline soil in the tsunami-affected area. The tsunami water that inundated the farmlands along the costs contained more or less the same dissolved salts. However, our concern is the different physical characteristics of the soil and the farmland, both of which may have major implications for remediation measurements and work. Yoshii et al. (2012) compared the salinity in soils following the 2011 tsunami in Japan and the 2010 tsunami in Chile and pointed out the significance of a proper assessment in determining the characteristics of the inundation area.

3.2 *Major soil properties*

Fig. 4 presents the variation in the average EC values (field test and lab analysis) of the surface soil at the different sampling locations. In both tests, Minamisanriku cho showed the highest level of salinity (field test: 3.72 dS m^{-1}, lab test: 2.43 dS m^{-1}) in tsunami-inundated surface soil among the sampled locations in Miyagi Prefecture. The bar diagrams show the EC values at the corresponding inland and coastal locations for a single site (place). They indicate the original salinity level and the possible effects of the seawater/tsunami deposits, respectively, at the surveyed sites. The analysis of the variation in the EC levels at these three different spots (C, T, and I) showed that the surface soil at the tsunami-inundated location of Minamisanriku cho had the maximum salinity, possibly due to the seawater intrusion. The average pH value of the surface soil at the tsunami-inundated sites varied within the range of 6.9 to 7.9, and the maximum and minimum OMC varied between 10.98% and 5.3% (in terms of percentage loss-on-ignition) at the Minamisanriku cho and Sendai shi sites, respectively. It is difficult to relate either the pH or the OMC values of the surface soil to the salinity only a year and a half after the incident (tsunami inundation) because of potential natural- or anthropogenic-induced physical changes in the soil. The physico-chemical and biological properties of the underlying (undisturbed) soil sampled during the survey provide a better indication of the status of the soil at a particular site and the underlying reasons for its salinity.

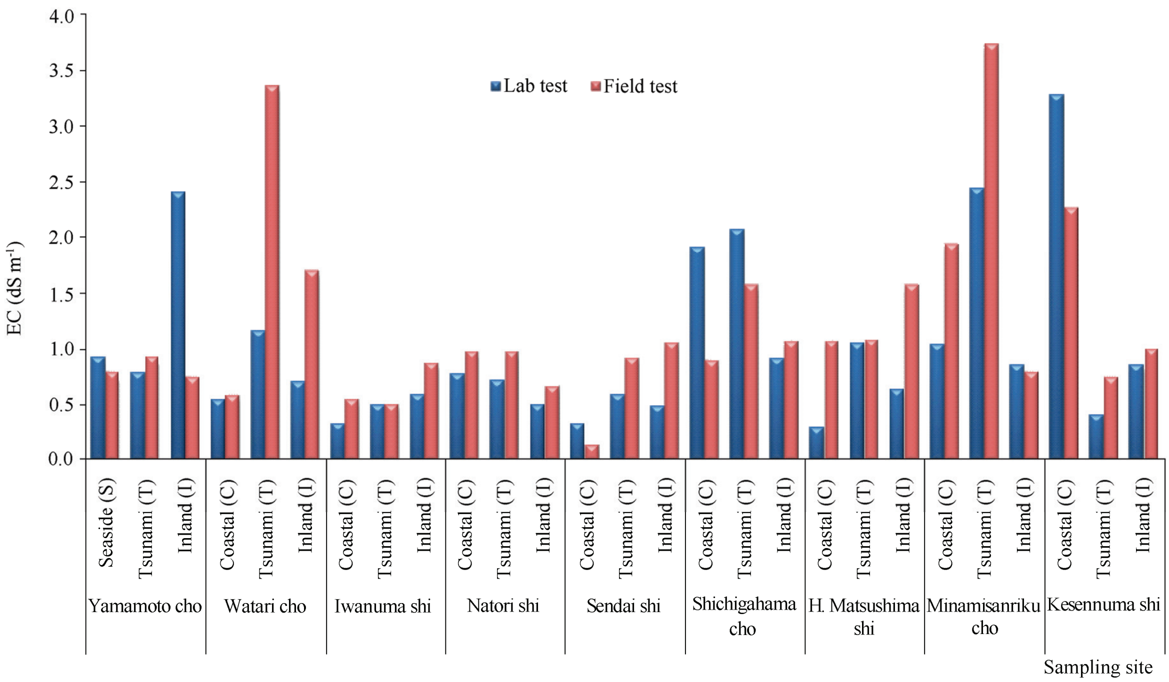

Fig. 4 Average EC values of surface soil at different sampling sites in Miyagi Prefecture (2012)

Table 3 shows the EC values, SHC, OMC, and particle size distribution of the core samples of underlying soil collected from the tsunami-inundated farmlands. Among the inundated sites, Watari cho and Shichigahama cho have the highest EC value (2 dS m^{-1}), with the nearby site of Yamamoto cho showing the lowest EC value (0.21 dS m^{-1}). Comparing the surface soil at the sites, the sites at Watari cho and Shichigahama cho have the highest EC values, followed by Minamisanriku cho, Iwanuma shi, Sendai shi, and Yamamoto cho (Table 3 and Fig. 2). To clarify possible reasons for the variations in the soil EC and the salinity level between the sites, Table 2 shows the values for other important factors that govern the infiltration, transfer, drainage, and water-holding capacity of agricultural soil. Lighter textured soils (such as sands or sandy loams) have higher infiltration rates due to the particle size distribution. On the other hand, heavy textured soils, which contain a lot of clay and/or silt, often have poor water penetration (infiltration/hydraulic conductivity) because the space that the soil occupies is relatively dense. Organic matter helps infiltration because it aids soil aggregation (resulting in larger soil particles). Comparing the underlying soil samples,Watari cho has the most heavy-textured soil and the largest proportion of finer particles (silt + clay = 82%),whereas Yamamoto cho has the most light-textured soil, containing 11% silt and clay. It can be assumed that the soil texture (sandy) at the tsunami-inundated site of Yamamoto cho facilitated the mitigation of salinity. Both the underlying soil and the surface soil at the Watari cho and Shichigahama cho sites have a higher amount of OMC (15.53% and 14.08%, respectively), which should contribute to the infiltration rates of the underlying soil. However, the salinity level of both the underlying soil and the surface soil is high. As Table 1 shows, there is little difference in the elevation of the three locations at Watari cho (C = 6 m, T = 5 m, and I = 6 m). The tsunami-inundated Shichigahama site lies below the coastal site (C = 5 m and T = 2 m). At these sites, stagnancy in groundwater movement and/or in-soil reverse flow from the coast to inland areas might delay the mitigation of salinity. The Minamisanriku cho site where the surface soil showed the maximum salinity and the underlying soil showed less salinity contains 68% silt and clay. This site had the second worst infiltration rate (2.0×10^{-5} cm s^{-1}) among the surveyed sites, followed by that of Natori shi (1.0×10^{-5}cm s^{-1}). As the tsunami-inundated site at Minamisanriku cho lies above the coastal site and far below the inland site (C = 7 m, T = 17 m, and I = 41 m), it can be assumed that the effect of surface runoff was much greater than that of the infiltration rate because of the relative physical position of the surveyed farmlands.

Table 3 Major physico-chemical and biological properties of underlying soil at the tsunami-inundated locations in Miyagi, 2012

Area	EC	OMC	Particle size distribution			SHC	
			sand	silt	clay		
	dS m^{-1}	%		%		cm s^{-1}	Rank
Yamamoto cho	0.21	2.78	89	1	10	1.1×10^{-3}	4
Watari cho	2.0	15.53	18	38	44	3.5×10^{-3}	2
Iwanuma shi	0.76	5.65	—	—	—	1.9×10^{-3}	3
Natori shi	1.32	8.73	—	—	—	1.0×10^{-5}	8
Sendai shi	0.53	4.27	—	—	—	9.1×10^{-5}	6
Shichigahama cho	2.0	14.08	51	46	3	6.1×10^{-3}	1
Higashimatsushima shi	0.73	4.77	33	62	5	1.7×10^{-4}	5
Minamisanriku cho	0.35	8.46	32	67	1	2.0×10^{-5}	7
Kesennuma shi	—	—	—	—	—	—	—

— Not measured.

Note: EC: electrical conductivity; OMC: organic matter content; SHC: saturated hydraulic conductivity.

3.3 *Major water-soluble ions*

The accumulation of sodium chloride (NaCl) is the main reason for salinization in agricultural soil exposed to tsunami water. Unlike Na^+ ions, which attach to clay particles, chlorides (Cl^-) do not associate strongly with soil and are washed out easily by rainfall. Figure 5 shows the concentrations of Na^+ and Cl^- ions in the surface soil in the tsunami-inundated site and the inland site. Table 4 shows other major ions (K^+, Mg^{2+}, Ca^{2+}, NO_3^-, SO_4^{2-}, and NH_4^+) measured in the study. Although the topsoil of the flooded areas showed a much higher concentration of these elements shortly after the tsunami (Chague-Goff et al., 2012), the concentration decreased as time passed (after a year and a half). Fig. 5 illustrates that in general there were higher levels of both Na^+ and Cl^- ions in the soils of most of the tsunami-inundated locations compared with the nearby inland site (except the level of Na^+ was higher at the inland site of Iwanuma shi). The concentration level of salinity varied from place to place, with Minamisanriku cho distinguished by a high value of both ions (Na^+ and Cl^-) and Sendai shi having a high value of Cl^- ions. The surface soil at Minamisanriku cho also had the highest EC value (Fig. 4), as well as the highest Na^+ concentration (25.8 mg L^{-1}). Although there were sharp elevational differences among the three sites at Minamisanriku cho (Table 2), due to the sites' heavy soil texture and reduced infiltration rate (Table 3), the salts were not leached to the underlying layer (Table 2). Thus, Minamisanriku cho had the most saline soil in

Miyagi Prefecture. The elevations of the three sites in Sendai shi were as follows: I = 3 m, T = 2 m, and C = 9 m. The underlying soil had a lower infiltration rate in common with that at Minamisanriku cho, indicating a favorable environment for water logging and/or reverse in-soil water flow from coastal to inland areas. Table 4 shows the measured value of the major ions (K^+, Mg^{2+}, Ca^{2+}, NO_3^-, SO_4^{2-}, and NH_4^+). As can be seen in this table, the tsunami-inundated site at Sendai shi shows extremely high concentrations of K^+ and SO_4^{2-}. The reason for the elevation in K^+ and SO_4^{2-} levels may be the same because both these elements are mainly formed in soil due to drainage or disturbance in waterlogged conditions (Thomas et al., 2003).

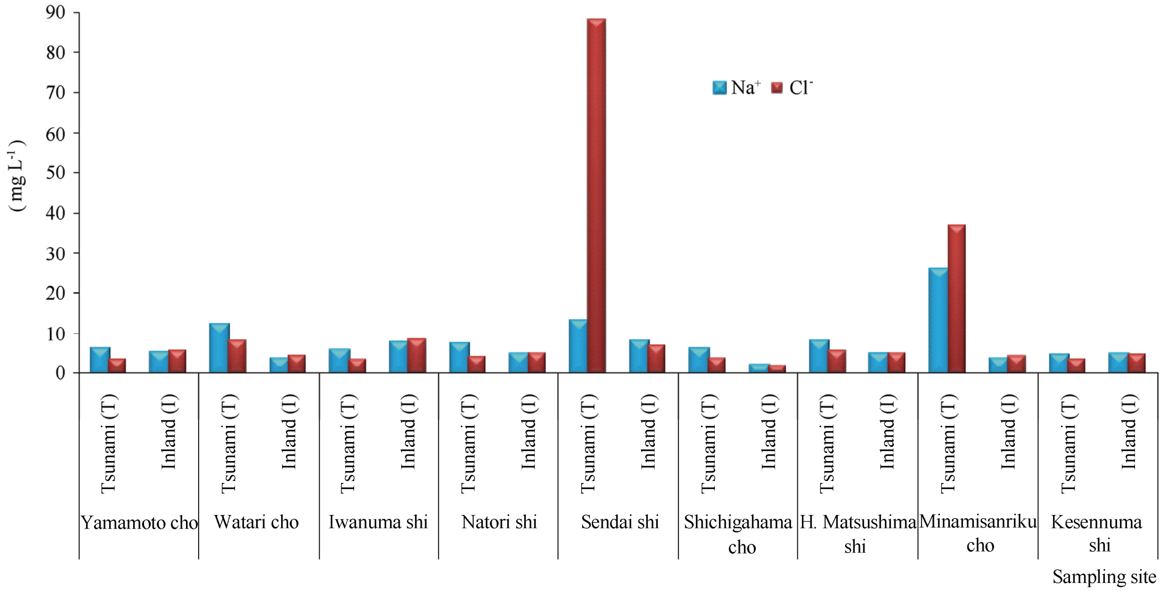

Fig. 5 Values of Na^+ and Cl^- ions in the surface soil in the tsunami-inundated sites and the inland sites in Miyagi Prefecture (2012)

Table 4 Values of major water-soluble ions in the surface soil of the different sampling sites in Miyagi Prefecture, 2012

Area	Location	Mg^{2+}	Ca^{2+}	NO_3-N	PO_4-P	SO_4^{2-}	NH_4^+	K^+
		mg L^{-1}						
Yamamoto cho	Tsunami (T)	0.5	1.4	0.3	0.3	2.7	0.4	3.5
	Inland (I)	0.9	3.0	0.7	0.9	1.7	0.8	5.7
Watari cho	Tsunami (T)	0.1	0.8	0.3	0.3	3.9	0.7	3.3
	Inland (I)	0.2	0.8	0.2	0.7	2.6	0.9	8.1
Iwanuma shi	Tsunami (T)	0.1	0.0	0.2	0.2	1.7	0.6	2.4
	Inland (I)	0.2	0.0	0.5	—	3.3	0.6	4.9
Natori shi	Tsunami (T)	0.7	1.2	0.2	0.3	2.2	0.2	4.2
	Inland (I)	0.1	0.7	0.2	0.7	1.0	0.6	3.3
Sendai shi	Tsunami (T)	1.2	0.0	0.8	0.4	15.0	1.1	98.5
	Inland (I)	0.2	0.8	0.2	0.3	2.1	0.8	3.5
Shichigahama cho	Tsunami (T)	0.7	2.6	0.2	—	7.3	0.5	3.7
	Inland (I)	0.3	2.5	0.8	0.2	1.5	0.2	4.3
Higashimatsushima shi	Tsunami (T)	0.1	0.5	0.2	0.1	5.9	0.6	1.8
	Inland (I)	0.5	1.8	0.6	—	3.3	0.3	2.1
Minamisanriku cho	Tsunami (T)	0.8	2.0	0.2	0.9	7.7	1.0	5.2
	Inland (I)	0.5	3.2	0.8	0.2	2.8	0.3	2.7
Kesennuma shi	Tsunami (T)	0.1	0.8	0.3	0.1	1.1	0.7	2.0
	Inland (I)	0.2	1.1	0.4	0.3	1.6	0.5	4.2

— below the detection limit.

4 Conclusion

From the analyses of major physico-chemical and biological properties in and around the tsunami-affected area in Miyagi Prefecture, the variation in the salinity level of the soil in agricultural farmland was due to differences in soil texture (particle size distribution) and the relative position (elevation) of the farmland, even in the same administrative region (prefecture). In most cases, the salinity was linked with one or more land and soil parameters. Changing the relative position of farmlands or changing the way in which agricultural land is reclaimed in Japan may be extremely difficult. However, attention needs to be paid to specific soil properties (such as soil texture) when remediating saline soil.

It is noted here that the lack of exact data on damage to irrigation and drainage facilities at each sampling spot and difficulties in distinguishing the make-up of the layer of the original surface soil at the crop root zone might influence the results of this study to some extent. Based on the results of this survey, we carried out another field survey in June 2013 where we concentrated on four field sites (Minamisanriku cho, Yamamoto cho, Watari cho, and Kesennuma shi). The survey focused on the salinity and the productivity of soil in reclaimed and nonreclaimed farmlands.

On-going experiments and trials are investigating the feasibility of using different alternatives for salinity mitigation in agricultural fields. The alternatives include the use of steelmaking slag materials, natural and artificial zeolite (alkali-treated coal ash), and highly salt-tolerant crops (phyto-remediation), such as cotton. We will continue and expand our field studies in other tsunami-inundated areas in the northeast region. Our ultimate goal is to develop site-specific and sustainable measures that will be accepted by local farmers to remediate soil salinity in agricultural lands.

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